UNIVERSIDADE FEDERAL DE SERGIPE

CENTRO DE CIÊNCIAS BIOLÓGICAS E DA SAÚDE

DEPARTAMENTO DE BIOLOGIA

BEATRIZ FERNANDES DE BARROS BOMFIM SANTANA

Foraminíferos da Formação Calumbi, Bacia de Sergipe-Alagoas e suas correlações com os eventos descritos para o Cretáceo Superior.

São Cristóvão-SE
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Orientador: Dr. Alexandre Liparini Campos

Trabalho de Conclusão de Curso apresentado ao Departamento de Biologia da Universidade Federal de Sergipe como requisito parcial para a obtenção do título de Bacharel em Ciências Biológicas.

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Revisado por: ____________________________________

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2017

AGRADECIMENTOS

Sempre imaginei como seria o dia em que finalizaria o período mais importante da minha vida e posso dizer que é muito interessante perceber como a vida sempre dá um jeito de superar e recriar todas as suas expectativas. Finalizar a etapa da graduação não simboliza somente o fim de um curso, ganhar um diploma ou receber o título de bióloga, representa uma mudança de fase, o início da busca por sonhos e o fim de um crescimento pessoal. Ao longo desses cinco anos dentro da biologia aprendi a olhar o mundo com outros olhos, amar a minha futura carreira e o mais importante, não desistir de tudo que sonho, por mais difícil que pareça. Por isso, no fim de mais uma etapa, agradeço as pessoas que deixaram a sua marca, de qualquer forma, ao longo desse período. Citar nomes é uma tarefa complicada, mas todos aqueles que não estão aqui e que fazem parte disso sabem o tamanho da minha gratidão. Meu muito obrigada a toda a minha família, fonte de toda a minha inspiração, principalmente meus pais Kátia e José Fernandes que do jeito deles, me mostraram o quão importante é fazer o que ama. Obrigada aos amigos muito especiais que ganhei dentro do curso, Andrea, Giulia, Juliana, Leoni, Damyres, Dário, Bel, Isabela, Jéssica e Weverton. Muito obrigada por toda a paciência com trabalhos, correção de textos, apresentações e análises estatísticas. Vou levar vocês pra sempre, não importa onde a Biologia me leve. Obrigada aos amigos que cresceram comigo, Larissa, Leila, Mary, Neto, Dudu, Ester, Léo, Nina, Catarine e Gabi. Crescemos juntos e acompanhamos as várias etapas da vida de cada um, que isso permaneça! Obrigada aos que se fizeram presentes e me ajudaram muito no início do curso, Tiago, Marcelo, May e Rafa. Mesmo distantes o apoio de vocês foi fundamental. Obrigada àqueles que mesmo recentes, me ajudaram mesmo que sem perceber, em algum momento do caminho. Hannah, Stéphanie, Victor, Raphael Bode e toda a galera que está todo dia no laboratório de Paleontologia da UFS. Não posso esquecer os amigos que fiz no ano mais especial da minha vida! Meus amigos de intercâmbio da CSUN e da UCSD que mesmo muito longe estão sempre torcendo e vibrando por mim. Agradeço ao apoio da Universidade Federal de Pernambuco através do Dr. Robbyson de Melo, com o auxílio na identificação do meu material. Por fim, muito obrigada aos professores da UFS que me ajudaram de alguma forma e ao meu orientador Prof. Dr. Alexandre Liparini por toda a paciência, calma e confiança ao longo desse ano. A sua orientação foi fundamental para o resultado final!

EPÍGRAFE

“However difficult life may seem, there is always something you can do and succeed at.”

Stephen Hawking.

RESUMO

The reconstruction of geological and paleoenvironmental events through paleoecological analysis is of great importance to understand possible climatic events and future ecological reactions.A Paleoecologia é um importante ramo da Ecologia que consiste em aplicar os conhecimentos e teorias ecológicos para os ambientes do passado, através da análise de organismos fósseis. O período Cretáceo é muito estudado pela sua condição climática ter sido definida como muito similar ao efeito estufa. A Formação Calumbi – Bacia de Sergipe Alagoas, pertence ao Cretáceo Superior e está associada a grandes eventos geológicos que interferiram nas condições ambientais para o período. O presente trabalho tem como objetivo determinar como esses eventos descritos para o cretáceo ocorreram para a Formação Calumbi através da identificação de formas fósseis de foraminíferos e análises paleoecológicas. Foram identificados cerca de 300 foraminíferos para cada amostra coletada no afloramento Calumbi 01, localizado em 10.882900 ° S, 37.117405 ° W, WGS 84, Nossa Senhora do Socorro, SE-Brazil.. O material foi retirado de três níveis, denominados de Superior, Intermediário e Inferior. A partir dos resultados da análise dos índices ecológicos e da diversidade Beta, além das análises feitas para o índice de oxigênio de cada nível a partir de foraminíferos bentônicos, verificou-se que os três níveis apresentam diferenças significativas entre eles e que eram ambientes oxigenados, apesar das espécies mais abundantes serem classificadas como subóxicas e estarem relacionadas a ambientes com baixas quantidades de oxigênio, o que pode inferir que esses ambientes sofreram com eventos de ressurgência e de transgressão. A profundidade e a temperatura também foram analisadas a partir de formas planctônicas, indicando ambientes rasos e quentes. Apesar das dificuldades em definir preferências ecológicas e de hábitats para as espécies identificadas, foi possível definir as características paleoecológicas para o afloramento 01 da Formação Calumbi.

Palavras-chave: Campaniano, Paleoclimatologia, Proxies.

Abstract

Paleoecology is an important area of Ecology that consists of applying ecological knowledge and theories to the environments of the past through the analysis of fossil organisms. The Cretaceous period is much studied because its climatic condition has been defined as very similar to the greenhouse effect. The Calumbi Formation - Sergipe Alagoas Basin, belongs to the Upper Cretaceous and is associated to large geological events that interfered in the environmental conditions for the period. The present work aims to determine how these events described for the Cretaceous occurred for the Calumbi 01 outcrop through the identification of fossil forms of foraminifera and paleoecological analyzes. About 300 foraminifera were identified for each sample collected in the Calumbi 01 outcrop, located at 10.882900 ° S, 37.117405 ° W, WGS 84, Nossa Senhora do Socorro, SE-Brazil. The material was removed from three levels, named Superior, Intermediate and Lower. From the results of the analysis of the ecological indexes and Beta diversity, in addition to the analyzes made for the oxygen index of each level from benthic foraminifera, it was verified that the three levels present significant differences between them and that they were oxygenated environments, Although the most abundant species are classified as suboxic and are related to environments with low amounts of oxygen, which may infer that these environments suffered from resurgence and transgression events. Depth and temperature were also analyzed from planktonic forms, indicating shallow and warm environments. Despite the difficulties in defining ecological and habitat preferences for the identified species, it was possible to define the paleoecological characteristics for outcrop 01 of the Calumbi Formation.

Key words: Campanian, Paleoclimatology, Proxies.

SÚMARIO

I. INTRODUÇÃO

As formas fósseis de foraminíferos são um objeto de estudo importante para a Paleoecologia e a Bioestratigrafia. Para a bioestratigrafia, fornecem evidências sobre a idade das rochas marinhas e para os estudos paleoecológicos apresentam fatos sobre os ambientes do passado, através da análise de diversidade de espécies, o número de espécies planctônicas e bentônicas e até a variação entre os diferentes tipos de morfologias. Sob um aspecto biológico, os foraminíferos pertencem ao Reino Protista, são organismos unicelulares e que constroem uma espécie de concha, ou testas, normalmente divididas em câmaras que são adicionadas conforme o foraminífero cresce. Dependendo da espécie, as câmaras podem ser formadas por componentes orgânicos, areia, carbonato de cálcio ou outras partículas agregadas. Devido à alta diversidade morfológica, a identificação destes organismos é baseada na diferenciação de suas testas. São encontrados em qualquer ambiente marinho, apresentando hábitos tanto bentônicos como planctônicos. Habitam os mais variados tipos de ambiente com uma alta especificidade para o meio em que se desenvolvem, o que reflete nos seus caracteres morfológicos, já que fatores ambientais físicos e químicos causam interferências no seu crescimento. Os foraminíferos estão entre os organismos que apresentam testa, mais abundante no ambiente marinho (Dodd & Stanton Jr, 1934). .

Como afirmaram Lipps e colaboradores (1979), grande parte dos estudos paleoecológicos utilizam grupos fósseis de foraminíferos como fonte e objeto de estudo. As informações sobre aspectos bióticos e abióticos de um ambiente deposicional assim como suas variações ao longo do tempo geológico, podem ser obtidas através de análises de assembleias de foraminíferos. Tais análises levam em consideração a percentagem entre formas planctônicas e bentônicas, a diversidade de espécies, a proporção entre os diferentes tipos de composição das câmaras de foraminíferos e a comparação com formas modernas (Culver, 2000).

O Período Cretáceo corresponde a um período muito estudado na paleoecologia e paleoceanografia pela sua atribuição a condições climáticas similares as do efeito estufa (Hu et al, 2012). O objeto de estudo para este trabalho corresponde ao afloramento 01 da Formação Calumbi, pertencente à Bacia de Sergipe-Alagoas, composta por sedimentação em plataforma continental e ambientes de talude (Koutsoukos, 1989). O período datado para a porção aflorante da formação Calumbi (Neocretáceo) corresponde a uma idade geológica marcada também por eventos anóxicos, definidos por uma grande deposição de material orgânico em ambientes marinhos (Jenkys, 2010). A porção emersa da Formação Calumbi tem como origem a linha de costa e se estreita progressivamente para o estado de Alagoas (Souza-Lima, 2001).

A presente monografia será apresentada na forma de artigo científico, composto por Introdução, Aspectos Geológicos da Formação Calumbi, Caracterização da Área de Estudo, Metodologia, Resultados, Discussão e Conclusão. Serão abordados os possíveis aspectos abióticos e bióticos que interferem na distribuição das espécies de foraminíferos amostrados, resultando em um possível cenário ecológico para um ponto geográfico da Formação Calumbi. Três níveis estratigráficos distintos de um afloramento foram comparados na tentativa de relacioná-los aos eventos globais descritos para esse período geológico.

II. MANUSCRITO

Foraminifera of the Calumbi Formation Sergipe-Alagoas Basin: paleoecological reconstruction in time and correlation with major Late Cretaceous events

Beatriz Fernandes de Barros Bomfim Santana[1]*, Robbyson Mendes Melo[2], Alexandre Liparini[1].

INTRODUCTION

In a natural environment we can easily notice the correlation between the organisms and the abiotic factors that interact with them, which characterizes ecology. The study of relations between ancient organisms and their habitats with environmental changes is known as Paleoecology. This branch of Ecology studies how these organisms have survived the various stages of environmental differentiation along the geological time scale (Gastaldo et al., 1996). Paleoecology consists of a growing field related not only to the reconstruction of physical past environments, but also to the analysis of geological and biological factors incorporated into them (Dodd & Stanton Jr, 1934).

Since its origin, the Earth is marked by climatic and geological events that helped establish the current environments and forms of life. The exploration of the resources available by early terrestrial life forms enabled the first environmental responses to the first interactions between abiotic and biotic factors, for example, 2 billion years ago, photosynthetic microbes transformed an anaerobic biosphere into an aerobic – The Great Oxygenation Event (Gross, 2015). After that, many variations in oxygen levels were recorded throughout the Earth's history, such as some anoxia events (OAEs – Ocean Anoxic Events) described for the Cretaceous period, where the oceans were practically devoid of oxygen and full of organic matter, which may be related to transgression events and can be observed in the stratigraphic records (Jenkys, 1980). Such geological and paleoecological events are analysed in order to reconstruct ancient environments and added to the correct ecological tools are able to assist in the preservation of current ecosystems, offering data about environmental changes through time (Jeffers et al., 2014).

Ecological Proxies are useful tools for paleoenvironments reconstructions, because they can replace data that cannot be measured directly, such as data from geologic, biological and chemical trace elements influenced by climate (Gornitz, 2009). Morphological characteristics of fossil organisms are useful in defining paleoenvironments, as the morphology of some fossil taxa may have been "shaped" by environmental factors (Dodd & Stanton, 1934). Identifying these morpho-traits it is possible to relate genera or species with specific habitats and its corresponding environment (Brett, 2008). The fossil forms of foraminifera are an important object of study for Paleoecology and Biostratigraphy. For biostratigraphy they give evidences about the age of marine rocks whereas for paleoecological studies they show facts about past environments through the analysis of species diversity, the number of planktonic and benthic species and also about the variation between the different kinds of their morphology. At a biological aspect, foraminifers a monophyletic group of Protista, characterized as unicellular organisms capable of secreting a type of an external shell or test, divided in chambers that are added as the individual grows (Armstrong & Brasier, 2005). The excellent preservation of this group in the fossil record occurs mainly due to their small size and the composition of their test, which may be calcareous or agglutinated, for example. This probably produces one of the best fossil record on the planet, as pointed out by Kucera (2007). They are marine organisms and can live at the ocean bottom – benthic: epifaunal or infaunal species – or at the water column like planktonic forms (Gadgil et al, 2015).

As Lipps and others authors (1979) argue, most paleoecological studies use fossil groups of foraminifera as a source and object of study. Information on biotic and abiotic aspects of a depositional environment as well as its variations over geological time can be obtained through analysis of foraminiferous assemblages. These analyses take into account the percentage of planktonic and benthic forms, the diversity of species, the proportion between the different types of composition of the foraminifera chambers and the comparison with modern forms (Culver, 2000). Benthic foraminifera are important environmental indicators because they colonize marine habitats ranging from estuaries to the deepest oceanic areas (Armstrong & Brasier, 2005). Still according to Armstrong and Brasier (2005), the presence and exploration along this large habitat range reflects on their morphological adaptations. In addition, the planktonic foraminifera provide information on oceanic temperature and salinity, with temperature being an important determiner of the latitudinal distribution for the group (Arnold & Parker apud Sem Gupta 1999 - Armstrong & Brasier, 2005).

The Cretaceous period is widely studied in paleoecology and paleoceanography due to its similarity to the greenhouse effect climatic conditions (Hu, et al 2012). Paleoenvironmental and paleoecological data from foraminifera are observed in many studies for the period, mainly in relation to the sedimentation change of the marine environment and anoxic events, their causes and consequences, such as changes in foraminiferous assemblage patterns, as in the works of: Gerta Keller (1988), Koutsoukos & Hart (1990) and Almogi-Labin (1993).

Following the above mentioned studies, this work permeates the areas of Paleoecology and Paleoceanography to describe biotic and abiotic aspects of the environmental changes that occurred in the Late Cretaceous (Campanian), in a tropical region of the recently broken up Pangea. To access this data we identified and compared three samples of foraminifera assemblages from an outcrop section of the Calumbi Formation – Sergipe-Alagoas Basin. Based on these analyzes the present work aims to clarify the following problems: Are the foraminifera found at the Calumbi Formation related to the global paleoenvironmental events described for the Late Cretaceous? Are there differences between the foraminifera found at the different levels of the outcrop? If so, what factors determine these differences? Recognizing the dynamics of local paleoenvironmental changes and its relation with widespread past events may contribute to understand better how future events, whether natural or anthropogenic, can modify marine environments mainly using foraminifer microfossils as an analysis tool.

Geological Settings

The Sergipe-Alagoas basin is a marginal sedimentary basin situated in the northeast region of Brazil limited by the Pernambuco-Paraíba Basin to the north and the Jacuípe Basin to the south (Figure 1). Its origin is related to the opening events of the South Atlantic Ocean during the Cretaceous. The depositional sequences that led to the evolution of the Basin are classified into: syneclise, pre-rift, rift and drift, according to Campos Neto et al. (2007). During these phases, there were intense tectonic events, marine incursions, sea level variations, transgressions and changes in sediment supply (Campos Neto et al., 2007). After an erosive sequence at the Late Cretaceous a transgressive sequence, at the drift phase, begun to accumulate the Calumbi Formation, regarded as a solpe environment, with influence of turbidity currents (Feijó, 1994). Microfossil biostratigraphy determine a Neoconiaciano to Holocene interval of deposition for the whole formation (Feijó, 1994). .

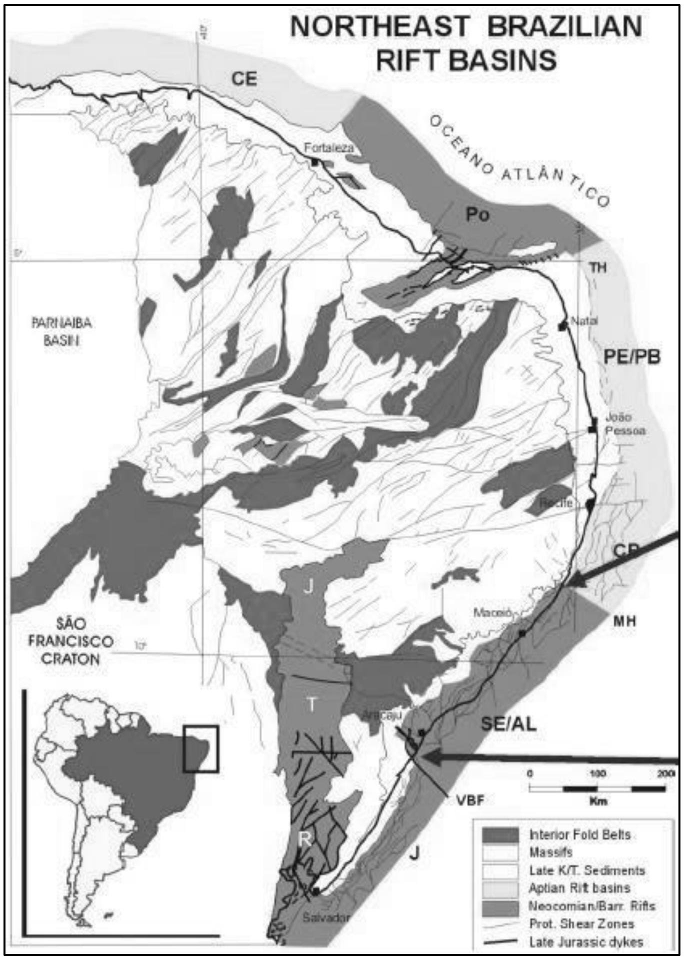

Figure 1. Sergipe-Alagoas basin limits.

Location Area

The outcrop Calumbi 01 is located at 10.882900 ° S, 37.117405 ° W, WGS 84, Nossa Senhora do Socorro, SE-Brazil. (Figure 2.) It was formed after two geological events: an erosion that occurred as a consequence of the sea level decrease at the end of Coniaciano and a transgressive event that generated a change in the sedimentation pattern, which changed from carbonate to silica (Souza-Lima & Cruz, 2001)**.**
According to Souza-Lima (2001) the Calumbi 01 outcrop is positioned for Upper Campanian and has high fossiliferous content, with a rich fauna of bivalves, gastropods, ammonia and vertebrates. However, this outcrop also has evidence of reworking, causing erosion and fragmentation of part of the fossiliferous content.

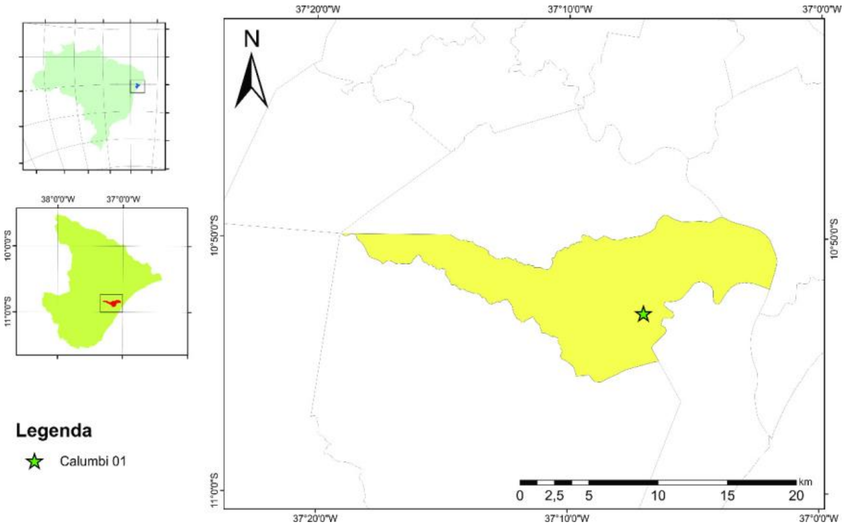

Figure 2. Calumbi 01 outcroup location.

MATERIAL AND METHODS

The methodology of the work consisted primarily in the gathering of sediment at different levels of an outcrop of the Calumbi Formation – Sergipe-Alagoas Basin, located in the city of Nossa Senhora do Socorro, State of Sergipe, Brazil – collected on three different levels: Upper, Intermediate and Lower, definidos a partir da distância de 2m do nível Intermediário, reconhecido como o mais fossilifero, in a section of ca. 5m. Para cada nível foi coletada uma amostra. The collected samples were stored in containers and taken to the LPUFS (Laboratório de Paleontologia da Universidade Federal de Sergipe) to be weighted. From the total of the collected sample, 200 g of sediment were weighed and placed in three different beakers with water so that the sediment sample was partially dissolved. After one day in the water, the samples were washed in running water over overlapped sieves of 1 mm and 63 micron respectively, so that samples larger than or equal to that diameter were kept in each sieve. Such material went into the greenhouse and dried at a temperature of 60 degrees Celsius. After drying, the samples were identified according to their locality of collection and were stored for microfossil analyses. For each stored sample 300 microfossils were randomly collected from and fixed on slides. The screening was done with the help of a stereoscopic magnifying glass and brushes. Microfossils were identified at a specific level with the aid of some identification books: The General Atlas of Identification of Loeblich and Tappan (1988), The Foraminiferal Benthic Fauna of the Upper Cretaceous – Arkadelphia Marl of Arkansas of Josheph A. Cushman (1942), Benthic Foraminifera Biostratigraphy of Bolli et al (2004). Além disso, com o auxílio do LAGESE – UFPE (Laboratório de Geologia Sedimentar, Universidade Federal de Pernambuco), foram feitas fotos de microscopia eletrônica de varredura e o aprimoramento dos espécimes já identificados.

In order to aid the Paleocological interpretations, comparison and determination of diversity patterns among the three levels, the results of some ecological indexes of diversity were analyzed using the PAST program, as the index of dominance, Shannon Heterogeneity Index, which represents the proportion of individuals that each species contributes to the total of the sample (the higher the index, the more similar the relative abundances and the greater the diversity), and the Jaccard Equity Index, which expresses how the number of individuals is distributed among the different species (Gomes, 2004). A diversity partition analysis was also performed together with the Whitattaker Beta diversity index and the similarity index, to compare the difference in species composition between the levels.

Finally, a cluster analysis was performed using the UPGMA interpolation coefficient. The beta and Shannon diversity indexes were also calculated in the statistical program R to check if the values obtained for each level were statistically different (i.e., $p<0.05$). Other indexes tested correspond to the BFOI (Dissolved Oxygen Index) proposed by Kaiho (1994), which estimates dissolved oxygen levels from calcareous benthic foraminifera species, calculated by: [O / (O + D)],.x 100, where O represents Oxic species and D dysoxic species. A proporção de espécies planctônicas e bentônicas para dados de paleotemperatura e paleoprofundidade também foram mensurados (Table 1). The degree of oxygenation for each species are listed in Table 2, as well as their ecological preferences.

RESULTS

A total of 997 foraminifera were collected, of which 548 were identified at a specific level and 449 at the generic level. 28 different species and 33 genera were identified, of these 10 species and 26 genera are benthic and 18 species and 7 genera are planktonic. All three levels seems to have a composition of similar species, but they have some significant differences variations between them as will be discussed below.

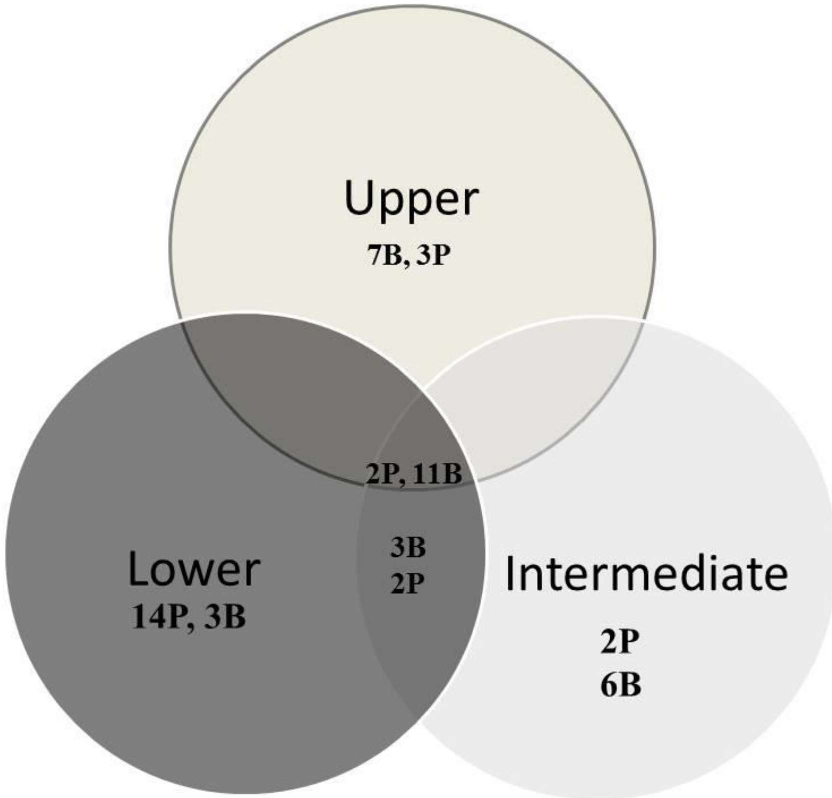

Figure 2. Foraminifera species distributed among the three levels. List of planktonic (P) and benthonic (B) species and genus as shown in Tables 1 and 2, respectively.

The ecological indices were calculated for planktonic and benthic foraminifera separately between the levels, since they provide different paleoenvironmental information (Figure 3). The lower level has the highest number of species (16) among the three levels, with *Praebulimina prolixa* being the dominant species. Even with this species presenting a high abundance for the lower level, this level apparently has a high index number of Equitability for benthic species (Figure 3), which reflects in a more uniform distribution among species abundances. The Shannon diversity index for the planktonic foraminifera of the lower level was higher when compared to the other levels for planktonic, classifying it as more diverse ~ 2.3. Some species are also present only in the lower level, mainly the planktonic ones, such as: *Laeviheteroelix glabrans Laeviheterohelix pulchra, Heterohelix navarroenses, Contusotruncana fornicata*, *Contusotruncana plummerae* and *Contusotruncana morozovae*, *Huberella huberi* and the genera Astacolus sp., Planulina sp., Bolivina sp and Gyroidina sp.

For the intermediate level, there is a decrease in the number of planktonic species (-12) in comparison to the lower level, an increase in the number of benthic species (+4) and, nevertheless, a decrease in the number of species of the genus *Praebulimina*, with the genus *Cibicides* as dominant. *Cibicides* may have contributed to the highest dominance index among the levels for benthic foraminifera ~ 0.17 (Figure 3). The genera *Gavelinella* sp. And *Citharina* sp. are exclusively identified for this level. The intermediate level has a numerically higher Equitability index for planktonic foraminifera ~ 0.86, which probably represents a better distribution among the individuals for each species of planktonic foraminifera.

Finally, the upper level shows a significant reduction in the number of species (-6), the number of planktonic species (-8) decreases. Some exclusive species recorded for this level were: *Guembelitria cretacea* and *Globotruncana aegyptiaca*. *Praebulimina prolixa* corresponds to the species with greater abundance, with a number of individuals much higher when compared with other species of the genus *Praebulimina*. For this level, the planktonic foraminifera presented a lower index number of Equitability, lower Shannon index and higher index number of Dominance (Figura 3), probably because the species *Guembelitria cretacea* present a much larger number of individuals when compared with the other planktonic species.

Both cluster analysis (benthic and planktonic foraminifera) grouped the intermediate and lower levels as more similar in their species composition than when compared to the upper level, which presents species that are more different and restricted. The result of the Beta diversity index (~ 0.7, with p value lesser than 0.05) indicates that the three levels present statistically significant differences in the composition of their species, both for benthic and planktonic species.

In relation to the paleoambiental reconstruction calculations, the dissolved oxygen content based on benthic foraminifera, for the lower level corresponded to ~80%, for the intermediate level 78% and for the upper lower level ~96%. Compared to the result presented for this index by Kaiho (1994), our results indicate levels with high oxygen rates formed by calcareous benthic foraminifera with dysoxic and suboxic enviromental preferences.

The planctonik/benthonic ratio, referring to the depth of each level, corresponded to approximately 35% for the upper level, which classifies the environment as inner neritic, 26% for the intermediate level and 30% for the lower level, classifying them as middle neritic. According to Koutsoukos & Hart (1990), foraminifera present in this paleodepth for the

Cretaceous of Sergipe are mainly calcareous-hyaline deposit-feeders species, mainly trophic groups with high diversity, represented mainly by epifanaul deposit feeders, plano-convex, concave-convex, low trochospiral morphotypes (gavellinelids), lenticular morphotypes and elongate tapered / straight morphotypes (buliminellids, nodosariids). Also according to Koutsoukos & Hart (1990), planktonic forms such as *Hedbergella* and *Macroglobigerinelloides* are also abundant for this depth.

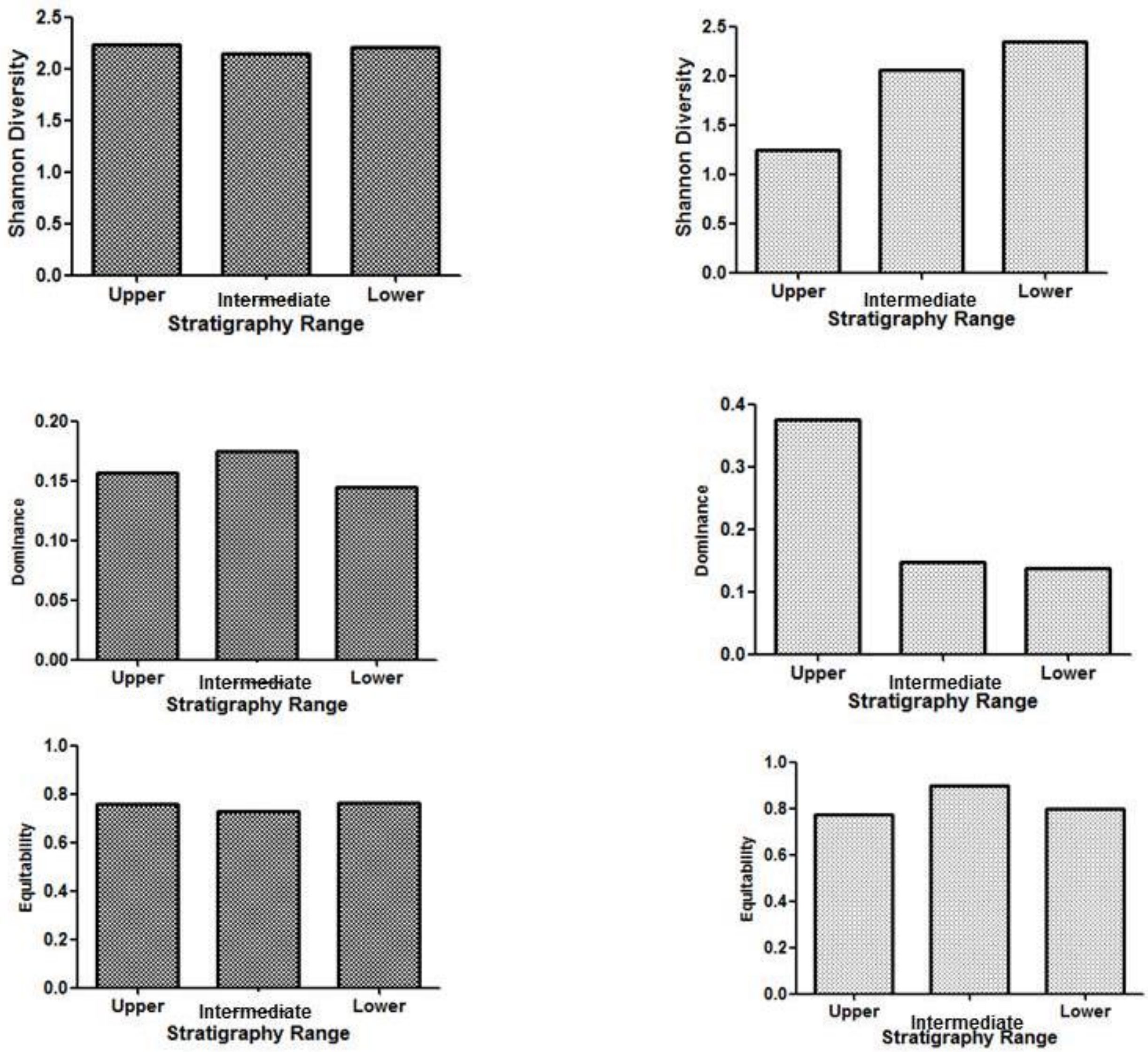

Figura 3. Graphs representing ecologic descriptors indexes- benthic (left) and planktonic (right).

Species/ Genera	**Paleotemperature**	**Level(s)**
Heterohelix globulosa	Cold*	U/I/L
Macroglobigerinelloides sp	Cold	U/I/L
Guembelitria cretacea	Warm	U
Guembelitria sp	Warm	U
Globotruncana aegyptiaca	Warm	U
Heterohelix sp	Cold	I/L
Macroglobigerinelloides boli	Cold	I/L
Hedbergella marmouthensis	Warm	I
Globotruncana arca	Warm	I
Maroclobigerinelloides praevolutus	Cold	I/L
Heterohelix navarroensis	Cold	L
Planoheterohelix globulosa	Cold	L
Laeviheterohelix sp	Cold	L
Contusotruncana fornicata	Warm	L
Contusotruncana plummerae	Warm	L
Constusotruncana morozovae	Warm	L
Contusotruncana sp	Warm	L
Huberella huberi	Warm	L
Laeviheterohelix glabrans	Cold	L
Laeviheterohelix pulchra	Cold	L
Hedbergella sp	Warm	L
Archaeoglobigerina blowi	Cold	L
Contusotruncana ackermani	Warm	I/L

Table 1. Planktonic Foraminifers and their paleotemperature.

Species	Environment	Living strategy	Oxygen Index	Level(s)
Neobulimina canadensis	Middle and lower slope areas	Infaunal	S	U/I/L
Neobulimina subregularis	Middle and lower slope areas	Infaunal	S	U/I/L
Neobulimina sp	Middle and lower slope areas	Infaunal	S	U/I/L
Praebulimina prolixa	Middle and lower slope areas	Innfaunal	S	U/I/L
Praebulimina spinatta	Middle and lower slope areas	Infaunal	S	U/I/L
Praebulimina fang	Middle and lower slope areas	Infaunal	S	U/I/L
Praebulimina bant	Middle and lower slope areas	Infaunal	S	U
Praebulimina reussi	Middle and lower slope areas	Infaunal	S	U/I/L
Praebulimina sp	Middle and lower slope areas	Infaunal	S	U/I/L
Stainforthia fusiformis	Intertidal-outer shelf and slope	Infaunal	S	U
Stainforthia sp	Intertidal-outer shelf and slope	Infaunal	S	U
Cibicides sp	Nearshore and intertidal	Epifaunal	O	U/I/L
Cibicidoides sp	Nearshore and intertidal	Epifaunal	O	U/I/L
Epistomia sp	Nearshore and intertidal	Epifaunal	O	U
Cystammina sp	Nearshore and intertidal	Epifaunal	S	U
Evolutinella sp	Nearshore and intertidal	Epifaunal	-	U
Nodosaria sp	Bathyal-abyssal	Semi-Infaunal	S	U/I/L
Bulimina sp	Intertidal-outer shelf and slope	Infaunal	S	I
Dentalina legumen	Bathyal-abyssal	Semi-Infaunal	D	U
Hanzawaya sp	Intertidal-outer shelf and slope	infaunal	O	I
Buliminella sp	Middle and lower slope areas	Infaunal	S	I
Eponides sp	Nearshore and intertidal	Epifaunal	O	I
Coryphostoma incrassatum	Intertidal-outer shelf and slope	Infaunal	D	I/L
Citharina harpa	Intertidal-outer shelf and slope	Infaunal	S	I
Astacolus sp	Nearshore and intertidal	Epifaunal	D	I/L
Pyramidina sp	Middle and lower slope areas	Infaunal	S	I
SiphoNodosaria sp	Bathyal-abyssal	Semi-Infaunal	D	L
Bolivina sp	Intertidal-outer shelf and slope	Infaunal	D	L
Gyroidina sp	Middle and lower slope areas	Infaunal	-	L

Table 2. Benthic Foraminifers and their ecological preferences

DISCUSSION

Foraminifers are widely used for paleoenvironmental reconstructions, their responses to environmental changes occur from morphological variations, changes in species composition and their patterns of abundance (Koutsoukos & Hart, 1990). In addition, there is an association between the distribution of these foraminifera and their habits, foraging strategies and the niches they occupy. Benthic forms, for example, have adaptation strategies and responses to the environment, such as the division between species that are r-strategists and k-strategists. Benthic foraminifera are very important as environmental indicators because of the great variety of habitats they are able to colonize, which reflects in their different morphologies due to the great exploitation of diverse resources (Armstrong & Basier 2005). Benthonic forms can be characterized as epifaunal, shallow infaunal species, deep infaunal species or just infaunal species. Epifaunal or shallower species need oxygen, available food, and oligotrophic conditions. Deep infaunal species are more tolerant to anoxic and eutrophic environments (Gooday, 2003).

On the other hand, paleoecological applications for planktonic foraminifera as Leckie (1987) affirm that simple, inflated forms inhabit near-surface waters, whereas flattened forms inhabit deeper habitats. The author further distributes the foraminifera in three groups: Epicontinental Sea Fauna, Open Marine Shallow Fauna and Open Marine Deep Fauna.

One of the most abundant benthic foraminifera taxa for the three levels corresponds to the species of *Praebulimina* sp. According to Oliver Friedrich and collaborators (2010), the genus *Praebulimina* is described for the Western Atlantic as present in eutrophic and low oxygen conditions, and it is characterized by Koutsoukos & Hart (1990) for Cretaceous foraminifera of Sergipe, as infaunal organisms and deposit feeders. *Praebulima prolixa* (Figure 4) and species belonging to the genus *Neobulimina* are described by Alegret & Thommas (2009) for the Pacific Northwest as tolerant to low oxygen and high flow of organic matter, in addition to linking *Praebulimina reussi* when dominant in an assembly, with environmental changes similar to the changes that occurred during the Cretaceous-Paleogene transition. Quilty (2002) portrays the dominance of the *Praebulimina* genus for Late Campanian-Maastrichtian samples taken from the Indian Ocean as shallow mid-slope environments, as described for paleodepth results.

Koutsoukos et al. (1990) relates the presence of *Praebulimina fang*, *Praebulimina prolixa* and *Praebulima reussi* with the interval corresponding to the Campanian, which also covers the Calumbi Formation, described in the above-mentioned work.

Other works also relate the presence of triseriate bulimides, such as the genera Praebulimina and Neobulimina to infaunal taxa, generalists, adapted to environments with low amounts of oxygen and high flow of organic matter, and also relates them to changes in the oxygenation pattern to the Upper Cretaceous and events of resurgence and transgression, as Kaiho (1994) describes in his work with Holocene faunas and Polivoda (2012) for samples from Israel and systems of resurgence and high productivity. The elevated levels of oxygenation and the high amount of Praebulimine recorded for the Calumbi 01 samples at all levels may be related to some short period of oxygen increase, similar to those occurring in the Upper Cretaceous after major anoxia events.

Alve (1994) describes the genus *Stainforthia* as a R-strategist taxon, colonizer of areas that have undergone a great environmental change and can survive in generalist environments, with a great variation of abiotic factors. They are resistant to anoxic conditions and when in abundance they characterize very oxygenated environments, which consequently relates it with very different atmospheres in its abiotic composition. On its distribution, occur in intertidal environments of continental shelf and slope, as well as described for the genus *Coryphostoma* by Beckmann (1988). The restriction of the genus *Stainforhtia* to the upper level of the Calumbi 01 may be related to the high oxygenation described for this level and the fact that *Stainforthia* sp has a high habitat range, inferring a very unstable environment for the higher level.

The genus Cibicides described in modern environments is related to a wide variety of habitats and depths, from mid to outer shelf, as well as the genus *Cibicidoides*, described for the same depths. Kaiho (1994) classify the genera as epifaunals and related to optical environments. In their work, Koustoukos & Hart (1990), attribute this genus to Campanian. The genera *Nodosaria* sp and *Dentalina* sp also define deeper neritic environments, near the platform limit (Venkatachalapathy & Ragothaman, 1995). The dominance of the genus Cibicides (Figure 4) sp for the intermediate level of the Calumbi 01 outcrop may be related to the oxygen indices for this level being high, giving a better adaptation when compared to other abundant benthic genera such as *Praebulimina*.

The low frequency of taxa adapted to very variable environments, such as *Eponides* sp (Speijer, 2002), *Heterohelix globulosa, Hedbergella monmouthensis, Planoheterohelix pulchra* and *Globigerinelloides volutus* described by Koutsoukos & Hart (1990) to the upper level of Calumbi 01 and the dominance of planktonic species such as *Guembelitria cretacea* and *Macroglobigerinelloides* sp (Figure 4) characterized by Polivoda et al (2013) as opportunistic species and adapted to very stressful environments of high productivity. This may suggest that the upper level had high productivity but with many variations in their environmental conditions and that these taxa were better competitors than other planktonic species that are present at low frequency to the upper level. The decrease in the quantity of planktonic species to the upper level may be related to this stress and high environmental variation defined to the higher level, establishing the survival of only some more generalist species.

Other planktonic species such as *Contusotruncana fornicata*, *Contusotruncana ackermani*, *Contusotruncana morozovae* and *Contusotruncana plummerae* are present at almost all levels (most occurring at the lower level) with the exception of the upper level. These species are described by Afghah and Ghiyasi (2013) as k-strategists, experts, indicators of warmer waters. Their presence at the same level of r-strategist taxa as the other species of heterohelicides, can infer the great environmental variation for this level, making feasible the occurrence of taxa so different. In addition, Abramovich et al (2003) defined that the occurrence of species with different ecological characteristics, as Bolivina sp (Figure 4) and Praebulimina sp may be related to marine incursion events, which alter the dynamics of the environment in which these species are inserted.

There are some difficulties in defining quantitative proxies for interpretations between the paleoenvironment and the associated faunas. Several external factors influence their life habits, such as sedimentation type, pressure, characteristics of the bottom water bodies, variations in the sedimentation environmental gradients, especially in areas near the continent, which receive more influences. Species are also able to tolerate a very large gradient of unfavorable conditions, in addition to the very inter- and intra-specific relationships that influence the dynamics of the community (Gooday, 2003).

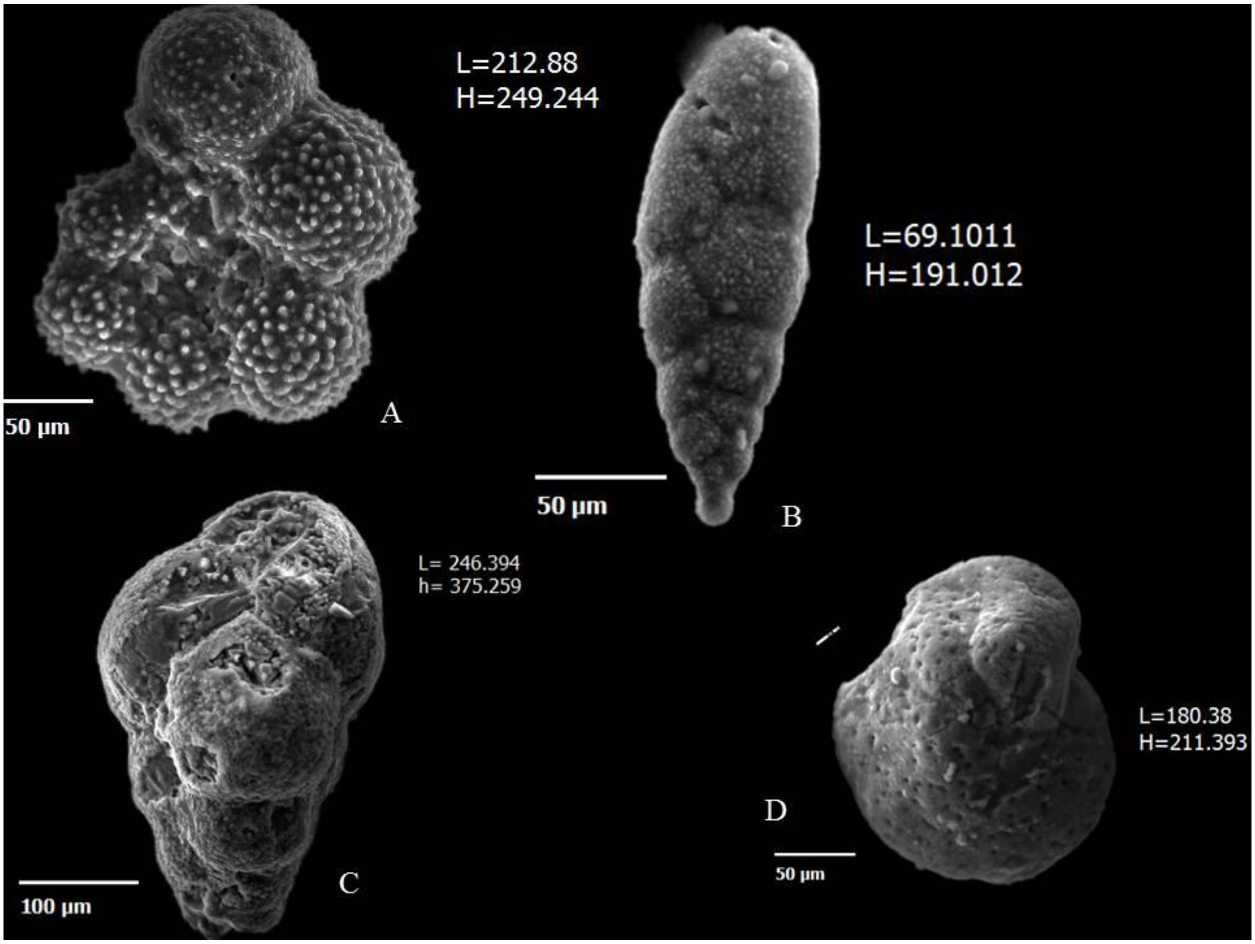

Figure 4: Some examples of foraminifers of the Calumbi 01 outcrop A *Macroglobigerinelloides* sp, B. *Bolivina* sp, C. *Praebulimina prolixa,* D. *Cibicides* sp. By: Robbyson Mendes de Melo – Pernambuco Federal University

CONCLUSIONS

Differences in species distribution between levels are represented in the result of the Beta diversity index, which characterizes them as different in their composition. The paleoenvironments analyzed for the Calumbi 01 outcrop seem to be related to warm oxygenated environments, continental shelf and platform, high variation of abiotic conditions, affected by transgression events, upwelling zones and their consequences, such as availability of food and oxygen. The prevalence of highly oxygenated levels and the presence of species characteristic of anoxic environments may be a result of these changes caused by variations in the sedimentation pattern, as well as the response of more biological factors such as the ability to survive in different environments, for example, the large number of tolerant suboxic species at different levels of oxygenation. The high abundance of generalist species such as those belonging to the genus *Praebulimina*, at all levels can be explained by these characteristics. The only exception is the *Cibicides* genus for the intermediate level, probably due to changes in depth, which decreased, and oxygenation patterns, which increased. The other species present may associate each level according to their particularities and provide a better interpretation: The unique presence of *Guembelitria cretacea* in the upper level and its ability to survive in very stressful and highly variable environments may associate the upper level as more unstable and possibly more affected by the effects of the Campanian transition and its geological events, or even with similar events, being more recent when compared to the other levels. The other levels probably are also associated with unstable environments, but to a lesser extent, by the occurrence of many species adapted to different environmental conditions.

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III. CONCLUSÃO

Apesar das dificuldades em atribuir características paleoecológicas definidas para espécies de foraminíferos e usa-las como objetos de interpretação, foi possível definir aspectos ecológicos gerais para o afloramento Calumbi 01 e entender de uma forma mais clara como fatores abióticos e no caso, eventos geológicos de larga escala, podem interferir na presença/ausência de organismos. A partir da análise das espécies amostradas para os três níveis, podemos inferir que trata-se de um ambiente inconstante, com grande variação ambiental, de águas quentes e rasas, o qual as espécies mais generalistas, capazes de sobreviver a hábitats variados, conseguem crescer em abundância. Além disso, a presença de espécies com preferências ecológicas variadas em um mesmo local indicam ambientes transgressivos ou influência de fenômenos de ressurgência. Os eventos descritos na literatura para o Cretáceo Superior foram responsáveis por grandes mudanças na Terra e sua interação com o paleoambiente é útil como modelo para a interpretação de possíveis eventos futuros.

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